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The ultimate goal of the project is to specify the transformations of the auditory stimulus used by the subject to determine the presence or absence of a signal when masked by an interfering sound, with particular emphasis on the role of processes that compare information in the frequency domain and in the time domain, and on the relation between monaural and binaural processing. Traditional psychophysical procedures are combined with new techniques (molecular psychophysics), which allow the data to be examined in considerably greater detail. With these techniques, conclusions and theories based on more general analyses are often shown to be inadequate. A number of experiments were conducted to evaluate models of monaural and binaural masking. The responses of subjects to individual noise-alone and signal-plus-noise waveforms could not be predicted based on the energy in a single auditory filter or a linear combination of several auditory filters. Responses to individual stimuli under monaural and binaural conditions were highly correlated, strongly questioning inter-
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19. Abstract (continued):

aural difference based models of binaural detection. The detectability of signals in the presence of maskers with changing level or interaural phase indicated that the binaural system responds relatively sluggishly to changes in stimulation. Measures of remote masking and suppression were found to be compatible with a nonlinear multiple filter model of peripheral processing. New measurement techniques were developed to better characterize subjects' responses to individual stimuli. Overall, the work examines issues and models of contemporary interest and thus has implications for auditory theory in general and for the study of auditory pattern analysis and auditory masking in specific.

BINAURAL MASKING: AN ANALYSIS OF MODELS

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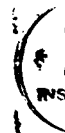Saint Louis. Missouri 63110

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Annual Technical Report
Binaural Masking: An Analysis of Models
Grant AFOSR 89-0302
R. H. Gilkey. Principal Investigator
April 1. 1989 to March 31. 1990

I. RESEARCH OBJECTIVES

The ultimate goal of the project is to specify the transformations of the auditory stimulus used by the subject to determine the presence or absence of a signal when masked by an interfering sound. with particular emphasis on the role of processes that compare information in the frequency domain and in the time domain, and on the relation between monaural and binaural processing. The study of auditory masking phenomena has far-reaching implications: 1) because. while all of auditory theory is based in whole or in part on the results of masking studies. the mechanisms underlying these phenomena are poorly understood: 2) because the noise reduction strategies used by the auditory system represent a basic form of auditory pattern analysis. which must be addressed when modeling more complex auditory processing: 3) because it is often critical to specify and to optimize human performance in noisy environments or through degraded communication channels; and 4) because the damaged ear has particular problems in noise. for which clinical solutions must be found.

Within our approach it is assumed that the behavior of a subject in a psychophysical task can be modeled by a system that on each trial computes a single "decision variable." which in the manner described by the Theory of Signal Detectability provides the basis of the subject's decision about the presence or absence of the signal. Within this framework the researcher's task is to specify this decision variable. For the r in-noise detection tasks we have been investigating. classical models would argue that the decision variable is based on the statistics of the stimulus within a narrow frequency region ccered around the signal (i.e.. the critical band) and within a brief temporal window that contains the signal. The results of experiments conducted during the previous funding period indicate that this classic view is an oversimplification and that the processing underlying tone-in-noise detection is better characterized as a form of simple pattern analysis. which compares information across different spectral/temporal channels. The goal of the current project is to examine further this simple pattern analysis by clarifying the processing within single spectral/temporal channels. across spectral/temporal channels that differ in frequency. and across spectral/temporal channels that differ in time. Particular emphasis is placed on the relation between monaural and binaural processing. Traditional psychophysical procedures are combined with new techniques (molecular psychophysics). which allow the data to be examined in considerably greater detail. With these techniques. conclusions and theories based on more general analyses are often shown to be inadequate. Thus. another goal of this project has been to develop more efficient and useful molecular psychophysical techniques.

II. SUMMARY

A number of psychophysical studies were conducted to evaluate models of monaural and binaural masking. The responses of subjects to individual noise alone and signal-plus-noise waveforms, whose frequency spectra were incremented or decremented in particular frequency regions, could not be predicted based on the energy in a single auditory filter or a linear combination of several auditory filters. Instead, it appears that some subjects may have altered their detection strategy in the presence of the complex auditory spectra. Responses to individual stimuli under monaural and binaural conditions were highly correlated for both wideband and narrowband masking stimuli, strongly questioning interaural difference based models of binaural detection. The detectability of signals in the presence of various maskers whose diotic level or dichotic phase changed as a function of time indicated that the binaural system responds relatively sluggishly to changing stimulation. Measures of remote masking and suppression were found to be compatible with a nonlinear multiple filter model of peripheral processing. Finally, new measurement techniques were developed to better characterize subjects' responses to individual stimuli.

III. STATUS OF THE RESEARCH

Our research on monaural masking and on binaural masking proceeds in parallel, with considerable interdependence. Additional support for this research has been provided by NSF (BNS-87-20305) "Analysis of models of auditory masking," period of support January 1, 1988 through June 30, 1989. R.H. Gilkey, PI.

Molecular psychophysical analyses of models of masking

Introduction. Many of our experiments use techniques that are different from those that have traditionally been employed in psychoacoustic research. Because many readers may be unfamiliar with these techniques, we begin by describing the overall approach and contrasting that approach with more classical methods.

In most studies of auditory masking, both the stimulus and the performance of the subjects are described by their statistical properties (e.g., the average power in the stimulus and the average probability of a correct response). The outputs of models are described by their distributional properties and the average performance of a model is fit to the average performance of a subject. Often, this "molar" approach is a little like noting the fact that the average annual temperatures in Saint Louis (66°) and San Francisco (66°) are similar and thereby concluding that the two cities have similar weather patterns. Another approach was described by Green [Psychol. Rev. 71: 392-407, 1964] and referred to as "molecular" psychophysics. In this approach, reproducible noise is used as a masker, such that the stimulus can be specified exactly on every trial. Thus, the response of the subject to each individual sound waveform can be measured. Computer models of human performance are evaluated not only by their ability to predict the average response, but also the response to each individual waveform.

Using these molecular techniques we have been reexamining traditional auditory theories. For example, it has typically been assumed that performance in simple masking tasks can be modeled as if processing occurred within single auditory filters, "critical bands." However, our data suggest that even in very simple masking situations, more complicated processes, which compare information across different spectral and temporal regions, must be introduced in order to model the behavior of the system. These processes act to compensate for fluctuations in the overall loudness of the stimulus and tend to accentuate sounds with peaks in certain frequency regions. The importance of these comparison processes is clear if one considers the listener in a "real world" situation, who cannot usefully monitor the absolute level of stimulus parameters, but must respond to the signal as a change in the complex pattern of auditory information. Gilkey and Robinson [J. Acoust. Soc. Am. 79, 1499-1510, 1986] and Gilkey and Meyer [J. Acoust. Soc. Am. 82: S92(A), 1987] used computer models to predict subjects' responses to the individual members of a large set of reproducible noise samples. The parameters of the models were manipulated until the outputs were best able to predict the subjects' responses to each of the samples. The combination of a 25 to 50-Hz-wide filter, followed by a half-wave rectifier and an integrator with a 40 to 200-ms decay constant, predicted their responses relatively well. However, a model that formed a weighted combination of the outputs of several detectors, each of which processed information in a different spectral region, yielded even better predictions and suggested that subjects compare the spectrum near the signal frequency to other areas of the spectrum. The obtained spectral weighting functions, which describe how the model weights information across frequency, can be interpreted as the difference between "excitatory" and "inhibitory" Gaussian-shaped weighting functions. These results strongly question classical critical band theory. Even though on average the subject's performance is unaffected by information that is outside a single critical band, when the responses to individual reproducible noise samples are investigated, it can be seen that the responses are dependent on the pattern of spectral information across a frequency range that is much wider than a single critical band. A similar model that processed information over different temporal intervals suggests that subjects also compare the waveform during the signal interval to the waveform immediately before the onset of the signal.

Molecular psychophysical techniques have also been particularly useful in illuminating binaural masking phenomena. The threshold of a low-frequency signal in a diotic noise is about 15 dB lower when the signal is interaurally phase inverted than when it is interaurally in phase (the Masking Level Difference, MLD). The MLD has been assumed to be related to the mechanisms that govern sound localization. Important for sound localization at low frequencies are the interaural differences in the arrival time of the stimulus. Thus, one major class of models assumes that binaural detection is based on interaural differences in time (and perhaps in intensity) [e.g., L.A. Jeffress, "Binaural signal detection: Vector theory" in J.B. Tobias (ed.), Foundations of modern auditory theory II, 349-368, 1972]. However, Gilkey, Robinson, and Hanna [J. Acoust. Soc. Am. 78: 1207-1219, 1985] showed that this class of models fails to predict significant aspects of the molecular psychophysical data. Specifically, the molecular psychophysical data indicate that performance is largely independent of the signal to masker phase relation, strongly dependent on the masker waveform even on noise alone trials, and highly correlated with the subjects' performance

under monaural conditions. None of these findings would be predicted by this class of models. On the other hand, Gilkey et al. were able to show that the Equalization-Cancellation (EC) model [N.I. Durlach, "Binaural signal detection: Equalization and cancellation theory," in J.V. Tobias (ed.), Foundations of modern auditory theory II, 371-462, 1972] generated predictions that were in at least qualitative agreement with each of these results. More recently we have implemented the EC model on the computer and used it to predict the responses of subjects to individual stimulus waveforms. Using bandwidths and integration times similar to those we had used for the monaural case and internal noise parameters consistent with the binaural literature, we were able to predict a substantial portion of the variance in the molecular psychophysical data. Significantly, when a multiple channel EC model was fit to the data, spectral weighting functions that agreed quite closely with those obtained for the monaural data were found.

In conclusion, molecular analyses show large and consistent differences in the responses of subjects across noise samples. Using these techniques we have gained new insights into the data and have been able to question long established models of auditory processing.

Detection in reproducible noises with altered spectra. If the spectral weighting functions derived by Gilkey and Robinson [op. cit.] and Gilkey and Meyer [op. cit.] provide a correct view of monaural processing, then it should be possible to add and subtract energy from different regions of the spectrum and change the observed value of P(y). Gilkey, Simpson, and Hammoud [J. Acoust. Soc. Am. 84: S140(A), 1988] selected 10 NA and 10 SN waveforms. The energy in each of the waveforms was raised or lowered by 6 dB in each of seven 47-Hz-wide bands, centered from one octave below the signal frequency to one octave above the signal frequency, yielding 280 "modulated" waveforms. A different waveform was presented on each trial of a block, and a substantial portion of these waveforms were unmodulated. Although changes in P(y) that result from decrements in the spectra are fairly small, in general, the pattern of results is that which would be expected based on spectral weighting functions derived from unmodulated trials. The pattern for increments is more complicated. Some subjects show very good agreement with predictions based on their spectral weighting functions. Other subjects show results that indicate that their detection strategy may have changed in the presence of the altered stimuli. Although the predicted "inhibitory" effects are observed at low frequencies, the "excitatory" effect is broader than anticipated, and little evidence of inhibitory effects is observed at high frequencies. This apparent conflict can potentially be explained by assuming that the subject looks for a peak in the spectrum anywhere near the 500-Hz signal frequency. Under normal circumstances a peak, if present, would probably be at the signal frequency. However, under the altered spectra conditions peaks can occur over a wide range. This strategy would be equivalent to monitoring the output of several weighting-function models like those of Gilkey and Meyer, each tuned to a different frequency regions, and choosing the largest output to use as a decision variable.

Preliminary investigations with a simple model using this strategy indicate that it is not able to predict responses to individual stimuli. Another approach that is planned is to employ the multiple band pass nonlinearity model [J.L. Goldstein, "Updating cochlear driven models of auditory perception: A model for nonlinear auditory frequency analyzing

filters." Working models of human perception, edited by B. Elsendoorn and H. Bouma, (Academic Press, N.Y.) pp. 19-57, 1989; J.L. Goldstein, "Modeling rapid waveform compression on the basilar membrane as multiple-bandpass-nonlinearity filtering." Hear. Res., in press, 1990|. This model is based on current knowledge of peripheral auditory processing, and would be expected to change its characteristics in a nonlinear manner in response to changes in stimulus intensity. A manuscript is planned.

The relation between monaural and binaural masking. The large masking level difference observed between monaural and binaural tone-in-noise masking tasks has been used to suggest that quite different processing is employed under the two conditions (e.g., energy detection vs. interaural time processing). However, when Gilkey et al. (op. cit.) examined the responses of subjects to individual wideband reproducible noise samples, they found that the responses under the N0S0 and N0Sπ conditions were highly correlated. On the other hand, when Isabelle and Colburn |J. Acoust. Soc. Am. 82: 109(A), 1987| examined the responses to narrowband reproducible noise samples, they found correlations that were much weaker and often negative. They attributed the differences between their data and those of Gilkey et al. to the differences in the bandwidth of the masker. If so, this would suggest that the correlation observed by Gilkey et al. would more appropriately be attributed to similarities in across critical band processing than to similarities in within critical band processing, as Gilkey et al. had implied.

To investigate further the effect of masker bandwidth, the experiment of Gilkey et al. was replicated using both wideband (100-3000 Hz) and narrowband (third octave) maskers. Although the correlation between N0S0 and N0Sπ performance was, in general, somewhat weaker for the narrowband condition all observed correlations were significant (p < <.001), reaffirming the strong correlation between N0S0 and N0Sπ performance. Again, this result has significant implications for models of both monaural and binaural performance. It is typically assumed that monaural performance is governed by the energy in the stimulus, while binaural performance is related to interaural differences in the stimulus, particularly interaural differences in time. The results of this experiment imply that binaural performance might be based on an energy-like cue (e.g., the EC model), or that monaural performance might be based on a timing-like cue (e.g., the model of Bilsen and Goldstein |J. Acoust. Soc. Am. 55: 292-296, 1974|).

Improved molecular psychophysical methods. Although the molecular psychophysical approach has proven extremely useful, data collection is slow; the amount of data is increased over that obtained in a molar experiment by a factor of approximately N, where N is the number of reproducible noise samples employed. Our approach requires us to estimate the value of the subjects' decision variable in response to each noise sample. In the past we have inferred this value based on binary responses in a simple yes/no detection task. The use of binary responses places a practical limit on the amount of information that can be transmitted on each trial (W. R. Garner and H. W. Hake, Psychol. Rev. 58, 446-459, 1951). In addition, the approach requires a number of additional assumptions that have not been tested, and the variability and the expected value of the estimate of the decision variable are not independent.

With these problems in mind. we have been developing a continuous rating procedure based on the procedure of Watson. Rilling and Bourbon [J. Acoust. Soc. Am. 36, 283-288, 1964]. The procedure is straightforward: the subjects' task is to use a mouse to position a cursor along the bottom of a CRT screen to indicate his confidence that a signal was presented on a particular trial. Positioning the cursor to the right of the screen indicates confidence that the signal was present. while positioning the cursor to the left indicates confidence that the signal was not presented. Initial evaluation of the procedure has been accomplished with two simple experiments. In the first. the subjects' task was to determine whether a particular three digit number presented on the CRT screen was drawn from a population of "noise alone" numbers or from a population of "signal plus noise" numbers. In the second. the subjects' task is to detect the presence of a tonal signal in the presence of a broadband noise masker. Overall. the results indicate that the subjects can, with training, produce reliable rating judgments. The expected value of these judgments appears to be a simple function of the stimulus magnitude. Ratings obtained to repeated presentations of the same stimulus are consistent. Thus, subjects' ratings can be used to reproduce stimulus distributions (i.e.. by deriving receiver operating characteristics or frequency histograms). Molecular psychophysical data collected with this technique will be compared to molecular psychophysical data obtained using binary responses.

Molar psychophysical analyses of models of masking

Binaural temporal masking. Because of the MLD. if the interaural phase of a noise masker is switched during the observation interval from in phase (N0) to 180° out of phase (Nπ) or from Nπ to N0. a brief interaurally out-of-phase signal (Sπ) will be about 15 dB more detectable in the N0 portion of the noise than in the Nπ portion. By investigating the change in detectability as a function of the delay (Δt) between the onset of the signal and the phase transition in the noise. the temporal response of the binaural system can be evaluated. The results of this case can be contrasted with a set of conditions in which the interaural phase of the noise is held constant (Nπ). but the level of the noise is reduced or increased by 15 dB halfway through the observation interval. Within a model such as the EC model (Durlach. op. cit.). the first case produces a change of level only in the binaural channel. The second case produces a change in the level in the monaural channel as well. The curves that describe the relation between threshold and Δt can be thought of as temporal masking functions. They show. like traditional temporal masking data. that the decay of backward masking (cases where the N0 segment of the noise precedes an Nπ segment or where the lower intensity segment of the noise precedes the higher intensity segment) is more rapid than for forward masking. Double-sided exponential integration windows have been fit to the forward and backward masking functions. The equivalent rectangular duration of the best-fitting window under monaural conditions ranges from 12-26 ms. somewhat larger than those estimated by Moore et al. [J. Acoust. Soc. Am. 83: 1102-1116. 1988]. The equivalent rectangular duration for the binaural conditions ranges from 41-83 ms. similar to estimates by Grantham and Wightman [J. Acoust. Soc. Am. 65: 1509-1517. 1979]. The observed differences between monaural and binaural conditions were taken as additional evidence that the binaural system responds sluggishly to changing stimulation [Grantham and Wightman. J. Acoust. Soc. Am. 63: 511-523. 1978]. A paper is in press [Kollmeier and Gilkey. J. Acoust. Soc. Am. 1990].

In studying the effects of a forward masker fringe. Yost |J. Acoust. Soc. Am. 78: 901-907. 1985| found that the threshold for a brief Sπ signal masked by a brief N0 masking noise was not changed when an Nπ forward masker fringe was added. This result was somewhat surprising in light of results such as those of McFadden |J. Acoust. Soc. Am. 40: 1414-1419. 1966| who showed that an N0 forward fringe substantially improved performance in an N0Sπ detection task. and concluded that the system uses the forward fringe as a diotic reference against which to detect the dichotic signal. If an N0 forward fringe provides a useful reference. it might be expected that an Nπ forward fringe would provide a detrimental reference. Yost's results also seemed to conflict with the interpretations of Kollmeier and Gilkey |op. cit.]. who thought of the Nπ fringe as a forward masker. One possibility was that the function that relates threshold to Δt for the Nπ forward fringe condition intersects with the function that relates threshold to Δt for the pulsed masker condition at Δt = 0. even though the functions are different elsewhere. To resolve these questions. the detectability of an Sπ tonal signal was investigated as a function of Δt. in the presence of an N0 "masker" that was preceded by quiet. or by an Nπ "forward fringe" and followed by quiet or by an N0 or Nπ "backward fringe." The results show that the functions for the Nπ forward fringe condition and the pulsed masker condition are indeed different and that they do not intersect. Overall. the results failed to replicate those of Yost. showing instead that the presence of either an Nπ forward fringe or an Nπ backward fringe reduces detectability for all subjects under a variety of conditions. The results are a further indication that the auditory system uses information that does not overlap with the signal in the temporal domain. Subsequent measurements indicate that the difference between Yost's results and ours cannot be explained based on differences in psychophysical procedure. the amount or type of training received by the subjects. or the duration of the signal. A manuscript is in press [R.H. Gilkey. B.D. Simpson. and J.M. Weisenberger. J. Acoust. Soc. Am. 1990].

McFadden |J. Acoust. Soc. Am. 83: 1685-1687. 1988| investigated the detectability of a brief tonal signal in the presence of a long duration masking stimulus. While the "overshoot" effect [E. Zwicker. J. Acoust. Soc. Am. 37: 653-663. 1965| was observed for diotic stimuli (N0S0). no overshoot was observed with dichotic stimuli (N0Sπ). (Overshoot is defined as the difference between the threshold for a signal whose onset is near the beginning of the masker. and the threshold for a signal whose offset is near the end of the masker). Comparable data |D.E. Robinson and C. Trahiotis. Percept. Psychophys. 12: 333-334. 1972: C. Trahiotis. T.R. Dolan. and T.H. Miller. Percept. Psychophys. 12: 335-338. 1972| indicate no overshoot under the monaural condition. but about 6 dB of overshoot under the binaural condition. We have recently replicated McFadden's experiment and found 4-8 dB of overshoot under both N0S0 and N0Sπ condition when a wideband masker is used. but no overshoot under either condition when a narrowband masker is used. The possibility that differences in signal frequency between the two studies influenced the results is currently being examined. Modeling efforts will focus on relating these data to those from the "pulsed masker" and "forward fringe" conditions described above.

Psychophysical evaluation of a physiologically based model of auditory processing. In the classical literature both the masking and the suppression of one tone by a second tone of lower frequency have been shown to be nonlinear functions of overall level. We are partially

replicating the experiments of Wegel and Lane [Physiol. Rev. 23: 226-285. 1924] on remote masking and of Duifhuis [J. Acoust. Soc. Am. 67: 914-927, 1980] on suppression, using modern adaptive psychophysical techniques and the same subjects in both experiments. The remote masking experiment measures the effect of a 602-Hz sinusoidal masker on the detectability of a simultaneous 1500-Hz sinusoidal signal, while the suppression experiment measures the effect of a 602-Hz sinusoidal suppressor on the forward masking produced by a 1500-Hz sinusoid. In addition, a simple forward masking measure is obtained in the absence of the 602 Hz suppressor. The data are comparable to those from earlier studies and agree with the Multiple Band Pass Nonlinearity (MBPNL) model (Goldstein, 1989, 1990, op. cit.). This model is based on current knowledge of auditory physiology and describes the response of the peripheral auditory system at each frequency as the result of a nonlinear interaction between a linear lowpass ("tail") filter and a compressive bandpass ("tip") filter. This view suggests that both excitatory and suppressive mechanisms influence remote masking. Estimates of the exponent of the compressive nonlinearity obtained from the simultaneous masking experiment agree with those obtained from the suppression and forward masking experiments. Reexamination of the simultaneous masking data that Gagné [J. Acoust. Soc. Am. 83: 2311-2321, 1988] obtained with hearing-impaired subjects, indicates that they are also compatible with the MBPNL model, if it is assumed that the tip filter is damaged (gain set to zero). The results of these experiments were presented to the Acoustical Society of America [Gilkey, Goldstein, and Quiñónez, J. Acoust. Soc. Am. 86 S24(A), 1989].

Remote masking and suppression experiments in the presence of a broadband contralateral stimulation were conducted to investigate the role of the efferent system, which is assumed to control the gain of the compressive tip filter within the MBPNL model. While the effects of the contralateral stimulation were relatively small, producing only a few dB of additional masking, the results were not incompatible with the predictions of the MBPNL model. We are currently planning experiments that will directly examine the effect of the efferent system on the response of the periphery by measuring distortion product otoacoustic emissions.

Consultants

Dr. H. Steven Colburn and Mr. Scott K. Isabelle of Boston University were brought in on a consulting visit from March 29 through April 1, 1990. With the help of additional funds provided by Central Institute for the Deaf, we were able to sponsor two seminars. The first, "Binaural hearing in impaired listeners," discussed the wide range of binaural capabilities observed in listeners with both conductive and sensorineural hearing loss. The second, "Modeling binaural detection: Problems with reproducible maskers," reviewed Dr. Colburn's and Mr. Isabelle's psychophysical work using narrowband reproducible maskers. Although some inconsistencies exist between the data from their laboratory and ours, in total, they provide a body of results that create severe problems for interaural difference based models of binaural detection.

The foundations for a more interactive relationship between the two laboratories were developed. Plans were made for high speed communication between our computing

facilities, allowing mutual access to data and modeling programs. The details of our experimental procedures and modeling strategies were compared. An important feature of the EC model and interaural difference models appears to be how the internal noise grows with stimulus level. It was also determined that some of the problems of the interaural difference models appear to be based on the particular nonlinearity employed (logarithmic) and that other compressive nonlinearities might yield superior results.

IV. PUBLICATION ACTIVITY

Publications

Kollmeier, B., and Gilkey, R.H. "Binaural temporal masking: Evidence for sluggishness in binaural detection." J. Acoust. Soc. Am., in press.

Gilkey, R.H., Simpson, B.D., and Weisenberger, J.M. "Masker fringe and binaural detection." J. Acoust. Soc. Am., in press.

Papers in preparation

Gilkey, R.H., and Partridge, M.E. "Direct-memory-access control of the Micro Technology Unlimited Digisound-16 with a Q-bus-based computer." for submission to Behavior Res. Methods, Instrumentation and Computers.

Meyer, T.A., and Gilkey, R.H. "Modeling subject responses in a reproducible noise masking task." for submission to J. Acoust. Soc. Am.

Planned papers

Gilkey, R.H. "The relation between monaural and binaural masking." planned for submission to J. Acoust. Soc. Am.

Gilkey, R.H. "Effects of manipulating the spectral shape of reproducible noise samples on the detection responses of human subjects." planned for submission to J. Acoust. Soc. Am.

V. PARTICIPATING PROFESSIONALS

Robert H. Gilkey

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University of California, Berkeley, CA	B.A.	1976	Psychology
Indiana University, Bloomington, IN	Ph.D.	1981	Psychology

Dissertation title: "Molecular psychophysics and models of auditory signal detectability."

VI. INTERACTIONS

Invited papers and conference talks

Goldstein, J.L., Gilkey, R.H., and Quiñónez, R.E. (1989). "A psychophysical evaluation of a model for suppression and excitation in remote masking." J. Acoust. Soc. Am. 86, S24(A).

Gilkey, R.H. (1990). "The relation between monaural and binaural tone-in-noise masking." Presented at the midwinter meeting of the Association for Research in Otolaryngology, St. Petersburg Beach, FL February 1990.